JUL 2 1987

Y 3.N88:25/4959

NUREG/CR-4959
PNL-6218

Performance Testing of Extremity Dosimeters

ORIGINAL

Prepared by R. Harty, W. D. Reece, C. D. Hooker

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

CDD

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082,
   Washington, DC 20013-7082
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG-series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Information Support Services, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-4959
PNL-6218

Performance Testing of Extremity Dosimeters

Manuscript Completed: April 1987
Date Published: June 1987

Prepared by
R. Harty, W. D. Reece, C. D. Hooker

Pacific Northwest Laboratory
Richland, WA 99352

D. O. Nellis and R. B. Neel, NRC Project Managers

Prepared for
Division of Regulatory Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN B2888

BEST COPY AVAILABLE

ABSTRACT

The Health Physics Society Standing Committee (HPSSC) Working Group on Performance Testing of Extremity Dosimeters has issued a draft of a proposed standard for extremity dosimeters. The draft standard proposes methods to be used for testing dosimetry systems that determine occupational radiation dose to the extremities and the performance criterion used to determine compliance. The draft standard has been evaluated by testing the performance of existing processors of extremity dosimeters against the standard's proposed criterion. The proposed performance criterion is: $|B| + S \leq 0.35$, where B is the bias (calculated as the average of the performance quotients) of 15 dosimeter measurements and S is the standard deviation of the performance quotients. Dosimeter performance was tested in seven irradiation categories: low-energy photons (general and accident dosimetry), high-energy photons (general and accident dosimetry), beta particles, neutrons, and a mixture category.

Twenty-one types of extremity dosimeters (both finger ring and wrist/ankle dosimeters) were received from 11 processors. The dosimeters were irradiated by the Pacific Northwest Laboratory (PNL) to specific dose levels in one or more of the seven categories as specified in the draft standard and were returned to the processors. The processors evaluated the doses and returned the results to PNL for analysis. The results were evaluated against the performance criterion specified in the draft standard.

The results indicate that approximately 60% of both the finger ring and the wrist/ankle dosimeters met the performance criterion. Two-thirds of the dosimeters that did not meet the performance criterion had large biases (ranging from 0.25 to 0.80) but small standard deviations (less than 0.15).

It was recommended that an effort be made to improve the biases by providing calibrations using appropriate irradiation standards and phantoms followed by another set of performance tests. In addition, visits should be made to processors to identify other possible sources of error. It is further recommended that the draft standard be re-evaluated to ensure that it is appropriate for the performance testing of extremity dosimeters.

BEST C[illegible]

SUMMARY

A draft standard entitled, "Standard for the Performance Testing of Extremity Dosimeters" (HPSSC P/N 13.32, June 1986) was prepared by a working group of the Health Physics Society Standing Committee (HPSSC) at the request of the Nuclear Regulatory Commission (NRC). This draft standard establishes the methods for testing dosimetry systems used to determine occupational radiation dose to the extremities. The draft standard also provides the performance criterion to be used to determine compliance of these systems. The final version of this HPSSC draft standard could be used to conduct performance testing of processors of extremity dosimeters. The performance testing would involve participation in a National Voluntary Laboratory Accreditation Program (NVLAP).

Before the NRC considers requiring accreditation of extremity dosimetry processors using the finalized standard, it is necessary to evaluate the appropriateness of the draft standard. The NRC contracted with the Pacific Northwest Laboratory (PNL) to conduct an evaluation of the draft standard. Results of the evaluation study are given in this report.

The study design is based on guidelines for the performance testing given in the draft standard. The draft standard specifies the sources and energy ranges to be used during the performance testing as well as the irradiation geometries and extremity phantom designs. In the draft standard, seven irradiation categories are specified in which the performance may be tested. The irradiation categories include low-energy photons (both general and accident dosimetry), high-energy photons (both general and accident dosimetry), beta particles, neutrons, and a mixture category. The low-energy photon category includes a subcategory for a nearly monoenergetic, low-energy photon source for plutonium environments. The beta-particle category includes a subcategory for uranium environments.

The performance criterion adopted in the draft standard was the following: the annual assignment of dose equivalent should be within 30% of the conventionally true value for 95% of the personnel receiving in excess of one-tenth of the maximum permissible dose equivalent. The derivation of the criterion assumed a dosimeter exchange rate of four times per year and approximately uniform exposures on each dosimeter. Because of the uncertainty in the assigned dose equivalent (which did not exceed ±5%), the performance criterion was set to: $|B| + S \leq 0.35$, where B is the bias of the dosimeter measurements (calculated as the average of the performance quotients) and S is the standard deviation of the performance quotients.

Eleven processors of extremity dosimeters participated in this study. The participants included six dosimeter processor vendors, four electric utility companies, and a medical research laboratory. A total of 21 different types of extremity dosimeters (both finger ring and wrist/ankle dosimeters) were submitted by the processors in the categories of their choice.

BEST COPY AVAILABLE

The test dosimeters were submitted by the processors in 3 separate groups. The processors sent the dosimeters required for the tests to PNL. The dosimeters were irradiated and returned to the processors before the next group of dosimeters was submitted. The doses were evaluated by the processors and then sent to PNL, where the test results were evaluated against the performance criterion. The test results were reported to the processors at the end of the test.

Using the performance criterion in the draft standard, 61% of the ring dosimeters and 57% of the wrist dosimeters passed the test. Approximately two-thirds of the dosimeters that did not pass exhibited standard deviations below 0.15. However, the biases accompanying these standard deviations ranged from 0.25 to 0.80, indicating that approximately two-thirds of the dosimeters that did not pass, failed as a result of the bias. This observation was further validated because the results tended to be processor-dependent. Some processors consistently passed each category they had chosen, while others consistently failed, or at best, barely passed. The latter processors frequently exhibited standard deviations that were not abnormally high and that fell in the range of the standard deviations exhibited by processors that passed. The biases, however, tended to fall on the extreme end of the range of the biases exhibited by passing processors. This indicates that the major source of error for failing processors is the bias. Although the bias may be affected by factors such as incorrect voltages in readout devices or mathematical errors, the primary cause is most likely incorrect or improper calibration.

Recommendations for improving the bias and thereby improving the performance of the processors include providing calibrations to the processors using appropriate phantoms and irradiation standards followed by another set of performance tests. The study should be enlarged to include additional processors to ensure that an appropriate sample has been obtained. In addition, visits should be made to processors to identify other possible sources of error.

It is further recommended that before finalization of the current draft standard, the testing procedures, the performance criterion, and the tolerance level should be re-examined to ensure that they are appropriate for the performance testing of extremity dosimetry. Specific areas that should be examined include:

Testing Procedures

- the extent to which processors of extremity dosimeters are aware of the exposure sources during irradiation in the workplace
- the magnitude of error resulting from not identifying the irradiation categories (excluding accident and neutron irradiation categories) for single chip dosimeters and a comparison of this error with the tolerance level set in the draft standard
- the selection of sources in multiple source categories.

Performance Criterion

- an investigation of the dosimeter exchange rate (the number of dosimeters worn annually by a given individual) to verify or discount the assumption of four dosimeter exchanges a year
- an investigation of the validity of the assumption of approximately equal doses on each of the extremity dosimeters worn by a single individual during a given year
- the inclusion of accident and nonaccident dosimetry under the same performance criterion.

Tolerance Level

- the validity of using a more stringent tolerance level for extremity dosimeters (in the nonaccident categories) than in ANSI N13.11 (ANSI 1983) for whole body dosimeters
- the possibility of using two separate tolerance levels. The lower level would be used for multielement dosimeters and for single-chip dosimeters in cases where the irradiation source has been identified. The higher tolerance level would be used for single-chip dosimeters where it can be demonstrated that the processor is unable to identify the source.

BEST COPY AVAILABLE

BLANK PAGE

CONTENTS

ABSTRACT iii

SUMMARY v

ACKNOWLEDGMENTS xiii

GLOSSARY xv

INTRODUCTION 1

PILOT STUDY PROCEDURES 3

- PERFORMANCE TEST DESIGN 3
- DOSIMETER HANDLING AND IRRADIATION PROCEDURES 3
- DOSE EQUIVALENT CALCULATION PROCEDURES 7
- TEST EVALUATION PROCEDURES 9

TEST RESULTS 13

APPROPRIATENESS OF THE DRAFT STANDARD 19

- THE TEST PROCEDURES 19
- THE PERFORMANCE CRITERION 20
- THE TOLERANCE LEVEL 22

CONCLUSIONS AND RECOMMENDATIONS 25

REFERENCES 27

APPENDIX A - ASSESSMENT OF UNCERTAINTIES A.1

APPENDIX B - COMPILATION OF DOSIMETER PERFORMANCE DATA B.1

BEST AVAILABLE

FIGURES

1 Summary of Performance (Ring Dosimeters) 14

2 Summary of Performance (Wrist Dosimeters) 15

3 Variation in Performance Based on Source 17

BEST COPY AVAILABLE

TABLES

1	Irradiation Categories	4
2	Exposure-to-Dose Equivalent Conversion Factors	8
3	Fraction of Processors Passing at Specific Performance Criteria Levels	23
A.1	Irradiation Uncertainties	A.4
B.1	Category I - Ring Dosimeters	B.2
B.2	Category II- Ring Dosimeters	B.3
B.3	Category IIIA - Ring Dosimeters	B.4
B.4	Category IIIB - Ring Dosimeters	B.5
B.5	Category IV - Ring Dosimeters	B.6
B.6	Category VA - Ring Dosimeters	B.7
B.7	Category VB - Ring Dosimeters	B.8
B.8	Category VI - Ring Dosimeters	B.8
B.9	Category VII - Ring Dosimeters	B.9
B.10	Category I - Wrist Dosimeters	B.10
B.11	Category II - Wrist Dosimeters	B.10
B.12	Category IIIA - Wrist Dosimeters	B.11
B.13	Category IIIB - Wrist Dosimeters	B.11
B.14	Category IV - Wrist Dosimeters	B.12
B.15	Category VA - Wrist Dosimeters	B.12
B.16	Category VB - Wrist Dosimeters	B.13
B.17	Category VI - Wrist Dosimeters	B.13
B.18	Category VII - Wrist Dosimeters	B.14

BEST COPY AVAILABLE

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the following persons: Becky T. Hogan, Keith K. Large, and Mark K. Murphy for performing the dosimeter irradiations; Fred N. Eichner for assistance with the phantoms; Lori S. Bisping, Sarah K. Bryson, Mike T. Crisp, Bryan M. Richardson, and Julie Thomas for assisting with the dosimeter preparation and shipment; Peter L. Roberson for providing the technical review; Peggy T. Upton for editing the report; and Marianna Cross and Sallie J. Ortiz for typing the report. In addition, we would like to thank the extremity dosimetry processors that participated in this study.

BEST COPY AVAILABLE

GLOSSARY

The definitions for terms used in this report are as follows:

absorbed dose (D) - The energy absorbed per unit mass at a specified point. The special unit is the rad. The SI (International System) unit is the gray (Gy). 1 Gy = 100 rad.

accident dosimetry - Determination of high levels of absorbed dose resulting from uncontrolled conditions.

bias (B) - The average of the performance quotients P_i, for n dosimeters, for a specified irradiation category and depth

$$B = \bar{P} = \frac{1}{n} \sum_{i=1}^{n} P_i$$

dose equivalent (H) - The product of the absorbed dose (D), the quality factor (Q), and any other modifying factors. The special unit is the rem. When D is expressed in Gy, H is in Sieverts (Sv). 1 Sv = 100 rem.

dosimeter - A combination of absorbers and radiation-sensitive element or elements packaged to provide a record of absorbed dose or dose equivalent received by an individual.

exposure-to-dose-equivalent conversion factor for photons (C_x) - The ratio of exposure in air to the dose equivalent at a specified depth in a material of specified geometry and composition. The C_x factors are a function of photon energy, material geometry (e.g., sphere, slab, or torso). and material composition (e.g., tissue-equivalent plastic, soft tissue ignoring trace elements, or soft tissue including trace elements).

extremity - That portion of the arm extending from and including the elbow through the fingertips, and that portion of the leg extending from and including the knee and patella through the tips of the toes.

extremity dosimeter - A dosimeter designed to be worn on an extremity.

extremity dosimetry system - A system used to assess dose equivalent from external radiation to the extremities. This includes the selection, placement, and processing of the dosimeters and the interpretation and documentation of the results.

free-field dose equivalent - The dose equivalent is assigned for neutron irradiation as if the irradiation were performed in free space with no background from air and room scattering and no source asymmetry (Schwartz and Eisenhauer 1982).

BEST COPY AVAILABLE

irradiation category - The type and energy (or mixture) of radiation for which performance criteria are given.

performance criterion - Used to evaluate dosimeter performance,

$$| B | + S \leq L$$

where B is the bias, S is the standard deviation, and L is the tolerance level.

performance quotient (P_i) - The fractional difference between the reported and delivered absorbed dose or dose equivalent for the i^{th} dosimeter,

$$P_i = \frac{[X_i \text{ (reported)} - X_i \text{ (delivered)}]}{X_i \text{ (delivered)}}$$

where D_d, H_s, or H_d can be inserted for X.

processor - A supplier of personnel dosimetry services. These services include:

- furnishing dosimeters to the user
- evaluating the readings of the dosimeters after their return in terms of the shallow and deep dose equivalents
- documenting the results
- reporting them to the user.

ring dosimeter - Any dosimeter worn on the fingers of hand to measure radiation dose.

shallow and deep absorbed dose (D_s and D_d) or dose equivalent (H_s and H_d) - The absorbed dose or dose equivalent at the respective depths of 0.007 cm and 1.0 cm in a material of specified geometry and composition.

standard deviation (S) - The standard deviation of the performance quotients, P_i, calculated for n dosimeters for a specified irradiation category and depth,

$$S = \sqrt{\frac{\sum_{i=1}^{n} (P_i - B)^2}{n - 1}}$$

testing laboratory - A group independent of the processor's operation and authorized by the organization administrating the accreditation program to carry out the procedures specified in the draft standard.

BEST COPY AVAILABLE

tolerance level - The level of uncertainty on the dose equivalent that is used to evaluate dosimeter performance. The value of the tolerance level is defined in the draft standard.

wrist dosimeter - Any dosimeter designed to measure radiation dose worn on the wrist or ankle.

BEST COPY AVAILABLE

INTRODUCTION

Radiation protection programs depend directly on correct measurement and quantification of radiation dose. However, radiation measurements are subject to a variety of potential errors and uncertainties. The quality of the measurement results depends on several factors including the quality of the detector system and the quality of the calibration techniques.

Based on the importance of providing accurate personnel dosimetry processing to radiation workers, the American National Standards Institute (ANSI) issued ANSI N13.11-1983 "Personnel Dosimetry Performance - Criteria for Testing" (ANSI 1983). This standard provides a procedure for testing the performance of suppliers providing dosimetry services to personnel who may be potentially exposed to ionizing radiation. In 1984, the Nuclear Regulatory Commission (NRC) issued a rule change (Federal Register 1984) to the Code of Federal Regulations, 10 CFR 20 (CFR 1981) for comment. This rule change would require NRC licensees to use the services of dosimetry processors accredited under the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Bureau of Standards (NBS) for dose measurements required by the NRC. On February 13, 1987, the commission approved a final amendment to 10 CFR 20 which requires NRC licensees to use accredited personnel dosimetry processors (Federal Register 1987). To be accredited, a processor would be required to pass performance tests as described in ANSI N13.11-1983. ANSI N13.11 applies only to personnel dosimeters (excluding direct and indirect reading pocket ionization chambers and those dosimeters used to measure the dose to hands and forearms, feet and ankles) whose readings are used to provide a lifetime cumulative personal irradiation record for an individual. However, the commission has agreed that the rule should be applied to extremity monitors as soon as a suitable performance standard is available.

A standard similar to ANSI N13.11-1983 was instituted by the Department of Energy (DOE) for the performance testing of personnel dosimetry (DOE 1986). The DOE Standard was based on the ANSI N13.11-1983 as well as on recommendations given in Roberson and Holbrook (1984) and on comments received during peer review by DOE and DOE Contractor personnel. The DOE Standard also does not address extremity dosimetry.

Although uniform standards governing the performance of extremity dosimetry systems do not yet exist, performance criteria for testing processors of extremity dosimeters are available in draft form. In March 1982, the NRC requested that the Health Physics Society Standards Committee (HPSSC) form a working group to prepare a consensus standard defining performance and quality assurance criteria for extremity dosimeter processors. That working group has prepared a draft standard, HPSSC P/N 13.32, "Standard for the Performance Testing of Extremity Dosimeters," June 1986. The draft standard establishes the methods for testing dosimetry systems that determine occupational radiation dose to the extremities and the performance criteria used to determine compliance. The draft standard also specifies the sources and energy ranges to be used during the performance testing as well as the irradiation geometries and extremity phantom designs.

BEST COPY AVAILABLE

The final version of this HPSSC standard (as published by ANSI) could be used to conduct performance testing of processors of extremity dosimeters. The performance testing would involve participation in a NVLAP proficiency testing program.

The U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, contracted with the Pacific Northwest Laboratory (PNL) to determine the appropriateness of the draft standard for the performance testing of extremity dosimeters. This determination must be made before the NRC can consider requiring accreditation of processors using the standard as a performance criterion. Thus, the design of this study is based on the guidelines for the performance test as given in the draft standard. Similar research projects involving the performance testing of personnel dosimetry services were conducted by the NRC in support of ANSI N13.11-1983 (Plato and Hudson 1980; Plato and Miklos 1983) and by the DOE in support of the DOE Standard (Roberson et al. 1983).

This report includes a description of the procedures used for the pilot study, an explanation of the results of the study and a discussion of the appropriateness of the draft standard. The procedures include a description of the performance test design, the dosimeter handling and irradiation procedures, the dose calculation procedures, and the test evaluation procedures. The discussion of the appropriateness of the draft standard addresses the tolerance level, the performance criterion, and the test procedures. Recommendations for the improvement of the draft standard are given in the final section of the report.

BEST COPY AVAILABLE

PILOT STUDY PROCEDURES

The pilot study procedures are based on the description of the performance test design given in the draft standard, HPSSC P/N 13.32, "Standard for the Performance Testing of Extremity Dosimeters," June 1986. This section provides a description of the performance test design, the specific dosimeter handling and irradiation procedures, the dose calculation procedures, and the test evaluation procedures used in this pilot study.

PERFORMANCE TEST DESIGN

The draft standard specifies seven irradiation categories in which processors may receive certification. From these seven categories, the processors select the irradiation categories for which they desire accreditation. The processors then send the dosimeters required for the tests. The test dosimeters for each category are submitted in three separate groups. The testing laboratory irradiates each group of dosimeters in turn and returns them to the processors before the next group of dosimeters are sent. The doses are evaluated by the processor and then sent to the testing laboratory, where the test results are evaluated against specific performance criteria. The test results are reported to the processor at the completion of each test.

The irradiation categories specified in the draft standard appear in Table 1 along with the sources specified for each category and the energy and dose ranges for each category. The categories include both accident dosimetry (doses of 10 to 500 rad) and occupational dosimetry (dose equivalents of 0.25 to 20 rem).[a] The categories include high- and low-energy photons, beta particles, neutrons, and mixtures. A nearly monoenergetic, low-energy, photon source (Category IIIB), and the uranium slab source (Category VB) were included for application to specific occupational environments. These categories were included for use in place of, or in addition to, Categories IIIA and VA, depending on the occupational environment covered by the dosimetry service.

DOSIMETER HANDLING AND IRRADIATION PROCEDURES

Eleven facilities that process extremity dosimeters were contacted to determine their interest in participating in this study. All eleven facilities chose to participate. The facilities include six dosimeter processor vendors, four electric utility companies, and a medical research laboratory. A list of the irradiation categories was sent to each of the processors, and they chose the category(ies) in which they wished to participate and indicated

(a) The test range for Category VA was lowered from the range given above to 0.15 to 10 rem because of the length of time required to irradiate dosimeters with the sources involved.

BEST COPY AVAILABLE

TABLE 1. Irradiation Categories

Category	Energy	Test Range	Test Depths
I. Low-Energy Photons (X Ray)- Accident Dosimetry		10 to 500 rad	Shallow
NBS Filtered Technique			
M150[a]	70 keV (average)		
II. High-Energy Photons- Accident Dosimetry		10 to 500 rad	Shallow
^{137}Cs[a]	662 keV		
IIIA. Low-Energy Photons (X Ray) - General		0.25 to 20 rem	Shallow
NBS Filtered Techniques			
M30[a]	20 keV (average)		
S60[a]	36 keV (average)		
M150[a]	70 keV (average)		
H150	120 keV (effective)		
IIIB. Low-Energy Photons (X Ray) - Plutonium Environments		0.25 to 20 rem	Shallow
Monoenergetic	15 to 20 keV		
Monoenergetic ^{241}Am	55 to 65 keV 59 keV		
IV. High-Energy Photons ^{137}Cs[a]	662 keV	0.25 to 20 rem	Shallow
VA. Beta Particles - General		0.15 to 10 rem	Shallow
^{204}Tl[b]	0.76 MeV (maximum)		
$^{90}Sr/^{90}Y$ (filtered)[a]	2.3 MeV (maximum)		
VB. Beta Particles - Slab Uranium		0.25 to 20 rem	Shallow
Natural Uranium	2.3 MeV (maximum)		
Depleted Uranium	2.3 MeV (maximum)		
VI. Neutron		0.25 to 20 rem	Shallow
^{252}Cf (moderated)[c]			
^{252}Cf (unmoderated)			
VII. Mixture Categories			Shallow
III. & IV.[a]	one energy from each category		
III. & V.[a]			
IV. & V.[d]			
III. & VI.[a]			
IV. & VI.[a]			

(a) This category or a subset of this category is specified in ANSI N13.11-1983.
(b) A modified performance algorithm is recommended.
(c) Moderated by 15 cm of D_2O (Schwartz and Eisenhauer 1980).
(d) For work environments containing plutonium, use the monoenergetic or ^{241}Am sources.

BEST COPY AVAILABLE

the type of dosimeter (ring or wrist) that they would submit. Several processors submitted more than one type of dosimeter. A total of 21 types of extremity dosimeters, including 12 types of ring dosimeters and 9 types of wrist dosimeters, were included in this study. Eleven of the ring dosimeters contained a single thermoluminescent (TL) element and one ring dosimeter contained two TL elements. Three of the wrist dosimeters were film dosimeters and the remaining wrist dosimeters were multielement TL dosimeters.

Most processors were willing to participate in several categories. However, because of the constraints imposed by this study, the number of dosimeters in each category was limited to 5 types of ring dosimeters and 3 types of wrist dosimeters. Many processors were thus unable to participate in all the categories they had requested.

The study was conducted in three rounds. For each round, the participating facilities shipped one group of 5 dosimeters for each of the categories in which they were participating. Eight to 10 extra dosimeters were sent with each shipment for each type of dosimeter, to be used as controls and spares. Upon receipt the dosimeters were counted, logged in, assigned a specific identification number, and organized into groups for irradiation. Dosimeters awaiting irradiation or shipment were stored in the same low-background area. The control dosimeters remained in the low background storage area while the actual irradiations were performed.

The dosimeters were all irradiated while placed on phantoms except for those exposed to the uranium source as specified in the draft standard. The uranium exposures were performed by placing the dosimeters directly upon the uranium slab. Two phantom types were specified by the draft standard: one to represent a finger to test ring or hand dosimeters, and one to represent a lower arm or leg to test wrist or ankle dosimeters. The finger phantom was a right circular cylinder constructed of methylmethacrylate with a diameter of 19 mm (3/4 of an inch) and a length of 610 mm. Two arm phantom designs were used: one for neutron exposure and one for photon and beta exposures. The arm phantom for the neutron exposures was a right circular cylinder made of solid methylmethacrylate. The neutron arm phantom had a diameter of 73 mm and was 610 mm in length. The arm phantom for the photon and beta exposures was constructed of a methylmethacrylate outer cylinder with an aluminum inner cylinder. The aluminum insert for the arm phantom used for photon and beta exposures was 60 mm (2-3/8 inches) in diameter and was nested inside the methylmethacrylate tube having an inner diameter of 60 mm and an outer diameter of 73 mm. The tubes were of the same length and were 457 mm long. The phantom designs were researched in a study supported by the DOE (Roberson, Eichner and Reece 1986).

Irradiations on the finger phantom were performed, when possible, in sets of 5 dosimeters. Irradiations on the wrist phantom were performed in sets of 3 dosimeters. The order of the dosimeters on the phantom was alternated each time. In most cases, no two dosimeters from the same processor were irradiated together. Thus, a suspected misirradiation could be checked by comparing dosimeter results from other processors. An exception occurred during Round 2 where one of the processors was unable to send ring dosimeters by the required

BEST COPY AVAILABLE

date. Because these dosimeters were not received on time, ring dosimeters from the remaining four processors in the affected categories were irradiated in groups of 5, requiring that 2 dosimeters from one processor be irradiated together. Suspected misirradiations could still be checked by comparing results obtained from the dosimeters of the other three processors. The dosimeters sent by the late processor were irradiated at a later date using the same dose levels but placing only 1 or at most 2 dosimeters on a phantom. Other situations requiring fewer than 5 ring dosimeters or 3 wrist dosimeters on a phantom, include neutron irradiations of the single ring dosimeter submitted in Category VI (performed by irradiating only 1 dosimeter on a phantom at a time), one set of two wrist dosimeters irradiated together in Category VI and irradiation of dosimeters in the mixture category (VII) during Round 2.

The sources specified by the draft standard for each of the categories are listed in Table 1. The draft standard specifies that for each category, except for the category specifically identified as that dealing with radiation mixtures (Category VII), only one type of radiation and one energy spectrum are to be used for all three rounds of a given test. However, for this study, the source used in the multiple-source categories was varied so that the study would identify variations in response to the different sources. The specific source used in each round of the test was randomly selected for each category from the list in Table 1. Exceptions include the ^{241}Am source, which was not available for Category IIIB, and the depleted uranium slab, which was the only source available for Category VB. The random selection occurred without replacement for categories containing three or more sources. Four of the processors participating in Category VII requested that their dosimeters not be included in mixtures containing neutron radiations. For these processors, a second selection of sources was made during Round 2.

The method specified in the draft standard for the selection of irradiation levels was suggested by ANSI N13.11-1983. This process involves the selection of random numbers, ρ, between 0 and 1. The logarithm of the dose equivalent, $_H$, is than calculated as:

$$\log {}_H = \log(_H)_1 + \rho[\log(_H)_u - \log(_H)_1]$$

where $(_H)_1$ and $(_H)_u$ are the lower and upper limits, respectively, of the test irradiation levels in question. The random selection of the logarithms of the irradiation levels rather than of the levels themselves increases the probability of selecting values near the lower limit of the range.

For collimated beams, the phantom was positioned so that the central beam axis was perpendicular to and passing through the center of the phantom. For uncollimated beams, the center of the phantom was perpendicular to the radial line from the source center. The calculation of the dose took into account the variation in radiation intensity at the position of each dosimeter on the phantom.

The specific dosimeters irradiated in each category were identified to the processors when the dosimeters were returned for evaluation. The source and the irradiation level used were not identified, except in Category VI

BEST AVAILABLE

where the source (moderated vs. unmoderated ^{252}Cf) was specified. The processors participating in Category VI were given the opportunity to indicate before the test the dosimeters that were submitted for the neutron tests. Pretest calibration exposures were provided for the neutron category. The ratio of a 9-inch diameter spherical rem meter and a 3-inch diameter sphere covered with 0.010-inch thick cadmium to provide a relative calibration for albedo dosimeters (Griffith et al. 1979) was also provided. This ratio is 2.70.

DOSE EQUIVALENT CALCULATION PROCEDURES

The dose equivalent assigned to dosimeters exposed to photons was calculated using the exposure-to-dose equivalent conversion factors (C_x) developed in a study jointly supported by the NRC and the DOE (Roberson, Eichner, and Reece 1986) and shown in Table 2. The dose equivalent for the photon irradiations using a sealed source, was calculated as:

$$H_s = Q \cdot C_{x,s} \cdot \dot{X}_{air} \cdot t$$

where the quality factor, Q, is 1.0, $\dot{X}_{air}$ is the exposure rate in air, s refers to shallow, and t is the irradiation time. The C_x factors for photon energies less than 1.25 MeV are shown in Table 2.

For x-ray exposures referenced to an unsealed monitor ionization chamber,

$$H_s = C_{x,s} \cdot T \cdot M \cdot C_{tp}$$

where T is the exposure-per-charge calibration factor for the monitor chamber at the standard temperature and pressure, M is the reading of the monitor chamber in units of charge, and C_{tp} is the temperature and pressure correction factor for the monitor chamber.

The dose equivalent assigned to dosimeters exposed to beta-particle fields was calculated using the equation:

$$H_S = \dot{D}_t(d) \cdot t \cdot Q \cdot C_{trans}$$

where $\dot{D}_t$ is the absorbed dose rate at the calibration depth d (7 mg/cm^2), t is the time, C_{trans} is unity, and the quality factor, Q, is 1.

Calculation of the free-field dose equivalent for dosimeters exposed to ^{252}Cf sources uses the following formula (Schwartz and Eisenhauer 1982):

$$H_d = \frac{N \cdot C_{UN} \cdot t \cdot 3600}{4\pi r^2}$$

BEST COPY AVAILABLE

TABLE 2. Exposure-to-Dose Equivalent Conversion Factors (C_x) for Photons (Roberson, Eichner and Reece 1986)

Filtered X-Ray Techniques	Conversion Factors (C_x) rem/R	
Technique	Arm/Leg Phantom	Finger Phantom
M30	0.99	0.95
S60	1.05	0.99
M150	1.14	1.01
H150	1.13	1.02
K-Fluorescence X-Ray Techniques		
Energy, keV		
16	0.96	0.92
23	1.00	0.96
31	1.03	0.98
40	1.06	0.99
59	1.13	1.00
75	1.14	1.01
98	1.15	1.02
Gamma-Ray Sources		
^{137}Cs	1.02	0.98
^{60}Co	1.00	0.98

where N is the neutron emission rate (n/sec), C_{UN} is the dose-equivalent conversion factor for unmoderated ^{252}Cf (3.33×10^{-5} mrem-cm^2/n), t is the time in hours, 3600 is the number of seconds in an hour, and r is the calibration distance (from the source center to the front surface of the phantom, cm).

For the moderated source, the following formula was used:

$$H_d = \frac{N \cdot C_M \cdot t \cdot 3600 \cdot 0.885}{4 \pi r^2}$$

where C_M is the dose-equivalent conversion factor for moderated ^{252}Cf (9.08×10^{-6} mrem-cm^2/n), and the 0.885 factor allows for the loss of the number of neutrons moderated below the cadmium cutoff.

The current flux-to-dose-equivalent conversion factors as specified in regulations and recommendations of the National Council on Radiation Protection and Measurements (NCRP 1971) are derived from the maximum value of dose equivalent in a 30-cm diameter cylindrical torso phantom. These values include secondary charged particles from neutron interactions as well as contributions from gamma rays from the absorption of neutrons by hydrogen atoms.

BEST COPY AVAILABLE

The cylindrical torso phantom model is not applicable for the extremities. However, for consistency, the flux-to-dose equivalent rate conversion factors recommended by the NCRP (1971) are applied in this study and in the draft standard until more pertinent information is available.

Typical values for the photon component are 7% of the neutron dose equivalent for unmoderated irradiations (Plato and Hudson 1980) and 18% for moderated irradiations (McDonald et al. 1983). These values were verified for PNL's irradiation facilities using neutron sources calibrated directly to NBS sources and the values were supplied to the processors. Because pre-test calibrations were given, corrections were not applied to the neutron dosimeter readings for scattering.

The radiation sources used in this study were calibrated directly or indirectly to NBS sources. The uncertainty in the assigned dose equivalent was calculated as given in Appendix A. The uncertainty did not exceed 5% (excluding uncertainties in the dose-equivalent conversion factors and in the photon component of the neutron irradiations).[a] The calculated uncertainty includes the following: the uncertainty in the source standardization, the uncertainty in positioning the dosimeter, the uncertainty in timing the exposure, and the uncertainty due to scattered radiations. The random uncertainties (positioning of the dosimeter, timing of the exposure, and source calibration) are summed quadratically. The ±5% limit applies to the linear sum of systematic uncertainties and one standard deviation calculated for the random uncertainties.

Dose-rate uniformity measurements were performed with the phantoms in place to determine the useful exposure area for each source. Position-dependent correction factors were used to comply with the uncertainty limits.

TEST EVALUATION PROCEDURES

The dosimeter performance was evaluated using the performance criterion specified in the draft standard. This performance criterion was used for the test evaluations in order to be consistent with the draft standard. The performance criterion used in the draft standard is based on the criterion derived in the Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems (DOE 1986). A similar performance criterion was specified in ANSI N13.11-1983. The performance criterion is:

$$|B| + S \leq L$$

where B is the bias, S is the standard deviation, and L is the tolerance level.

(a) Differing methods of interpolating quality factors can lead to a several percentage difference in the assessment of the dose equivalent. The values used for the photon component of the neutron irradiations were provided to the processors.

BEST COPY AVAILABLE

The performance quotient, P_i, is a measure of how close the reported or measured dose is to the true or delivered dose,

$$\text{where } P_i = \frac{[X_i \text{ (reported)} - X_i \text{ (delivered)}]}{X_i \text{ (delivered)}}$$

and X_i is the absorbed dose or dose equivalent. The performance quotient can also be termed the relative bias.

The bias, B, is the average of the performance quotients (or an average of the relative biases) of the dosimeters tested.

$$B = \bar{P} = \frac{1}{n} \sum_{i=1}^{n} P_i$$

The standard deviation, S, is a measure of the precision of the performance quotients or in other words, of how closely the performance quotients (relative biases) are grouped together.

$$S = \sqrt{\frac{\sum_{i=1}^{n} (P_i - B)^2}{n - 1}}$$

The standard of performance, the tolerance level, is based upon recommendations in the International Commission on Radiation Units and Measurements (ICRU) Report 20 (ICRU 1971) and in NCRP Report 57 (NCRP 1978). These reports recommend a 30% limit on the uncertainty of the dose equivalent in the vicinity of maximum permissible dose (MPD). For extremities (defined as "hands and forearms; feet and ankles"), the maximum permissible dose is given as 18-3/4 rem per calendar quarter (75 rem/yr) in 10 CFR 20 (CFR 1981). At one-quarter of the MPD, the NCRP allows as acceptable, a lower level of accuracy (e.g., a factor of 2). The ICRU suggests a factor of 3 on the uncertainty for doses of one-tenth the MPD. At higher doses, such as may occur during accidents, an accuracy of ±20% was considered appropriate by the NCRP. Early drafts of ANSI N13.11 included different performance criteria for various levels of dose. However, performance tests of whole-body dosimeters indicated that this was unnecessary over the typical range of dose equivalents (ANSI 1983). The time period over which the accuracy is achieved was not specified by the ICRU or by the NCRP. Thus, the performance criterion adopted in the draft standard approximately represents the requirement that the annual assignment of dose equivalent should be within 30% of the conventionally true value for 95% of the personnel receiving in excess of one-tenth of the maximum permissible dose equivalent. The derivation of the criterion assumed a dosimeter exchange rate of four times per year and approximately uniform occupational exposures.

Because of the uncertainty in the assigned dose equivalent (which did not exceed ±5% excluding uncertainties in the dose-equivalent conversion factors

BEST COPY AVAILABLE

and the photon component of the neutron irradiations), the performance criterion adopted in the draft standard was set to:

$$| B | + S \leq 0.35$$

Because of technical and practical limitations of current dosimeter designs, the test for the low-energy beta source (^{204}Tl) listed in Table 1 was set to:

$$| B | + S \leq 0.40$$

A discussion of the appropriateness of the performance criterion is given later.

BEST COPY AVAILABLE

TEST RESULTS

The bias (B) and the standard deviation (S) of the performance quotients were calculated for each model of dosimeter submitted for testing in each of the categories. The bias and standard deviation were calculated for each of the three rounds (5 dosimeters per round) as well as for the entire study (15 dosimeters). The sum of the absolute value of the bias and the standard deviation was calculated for comparison against the performance criterion. The results for ring and wrist dosimeters are addressed separately.

Appendix B contains the performance data for each type of dosimeter tested in this study. Appendix B is organized by irradiation category, and the processor code and dosimeter type codes are provided. Appendix B lists the irradiation source, the bias, and standard deviation for each of the three rounds of testing, as well as the bias, standard deviation, and the sum of the absolute value of the bias and the standard deviation that was calculated for the entire test.

The results of the dosimeter performance are plotted in Figure 1 (ring dosimeters) and in Figure 2 (wrist dosimeters). The bias, standard deviation, and the sum of the absolute value of the bias and the standard deviation ($|B| + S$) are plotted on separate axes for each processor in each of the categories. The data points are coded A through K to correspond to each of the 11 processors. Data points that are off scale in the positive direction are identified above each of the graphs. A dotted line is placed at 0.35 for the performance index to represent the tolerance level specified in the draft standard. A second dashed line is used to represent the tolerance level for the low-energy beta source (^{204}Tl) used in Category VA. Because of technical and practical limitations of current dosimeter designs, the draft standard specifies that irradiation tests with the low-energy beta source ^{204}Tl are compared to a tolerance level of 0.40. Although irradiations were performed with ^{90}Sr for two of the three rounds, applying the 0.40 tolerance level to the results of Category VA, a third ring processor (processor D) will pass.

For the ring dosimeters, the best performances were exhibited in Category II (high-energy photons, accident dosimetry) and in Category VII (mixtures), where 80% of the processors passed the test at the 0.35 tolerance level. The worst performances were observed in Categories I (low-energy photons - accident dosimetry) and in VB (beta particles - slab uranium), where only 40% of the processors passed at the 0.35 tolerance level. The single processor submitting a ring dosimeter in Category VI did not pass at the 0.35 tolerance level.

For the wrist dosimeters, the best performances were observed in Category II (high-energy photons, accident dosimetry) and in Category IV (high-energy photons), where 100% of the processors participating (3) passed the test at the 0.35 tolerance level. Categories I (low-energy photons - accident dosimetry), VA (beta particles - general), VB (beta particles - slab uranium), and VI (neutrons) all only had one processor pass. Thus, 33% of the processors in Categories I, VA, and VB passed and 25% of the processors in Category VI (where 4 processors submitted wrist dosimeters) passed.

BEST COPY AVAILABLE

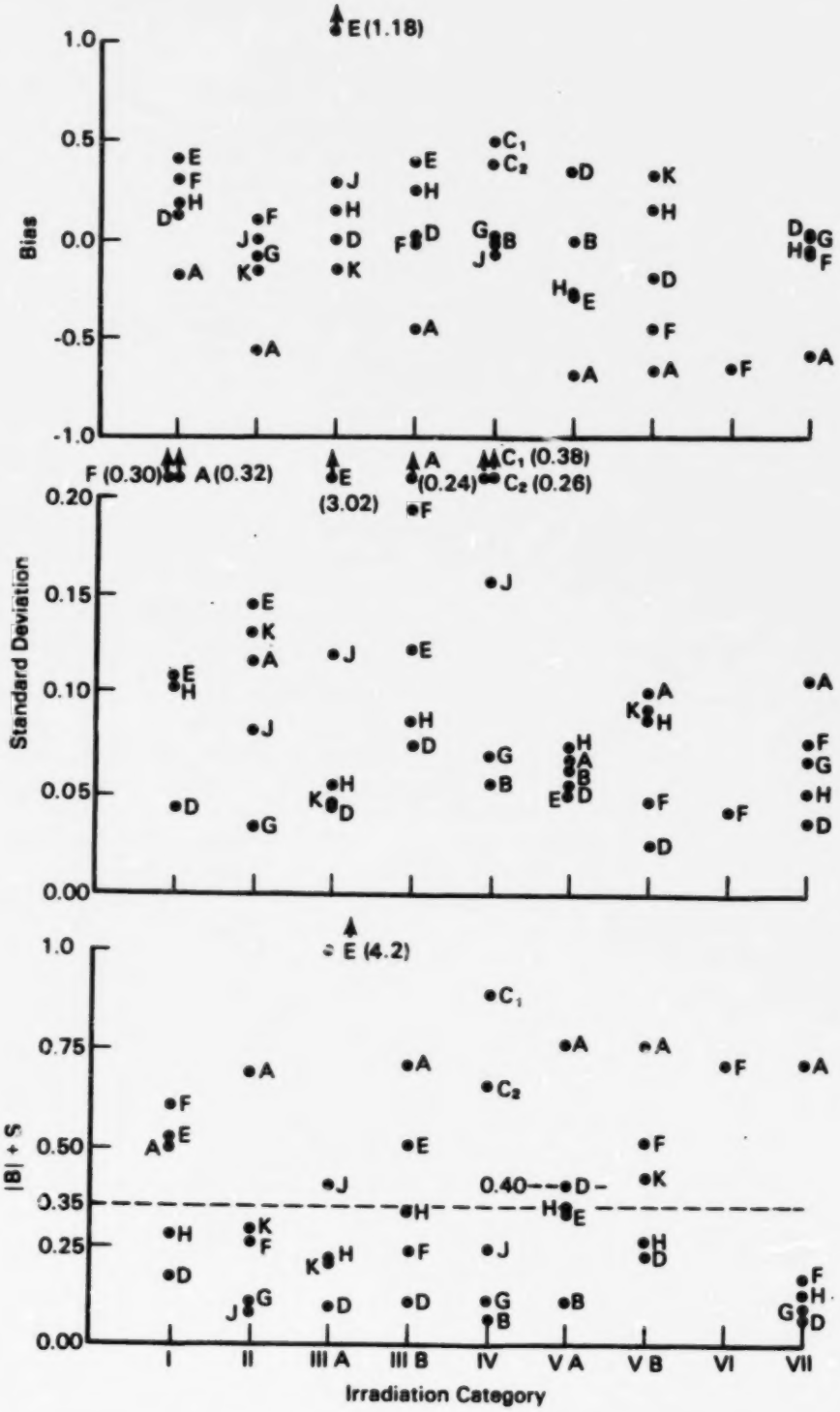

FIGURE 1. Summary of Performance (Ring Dosimeters)

BEST COPY AVAILABLE

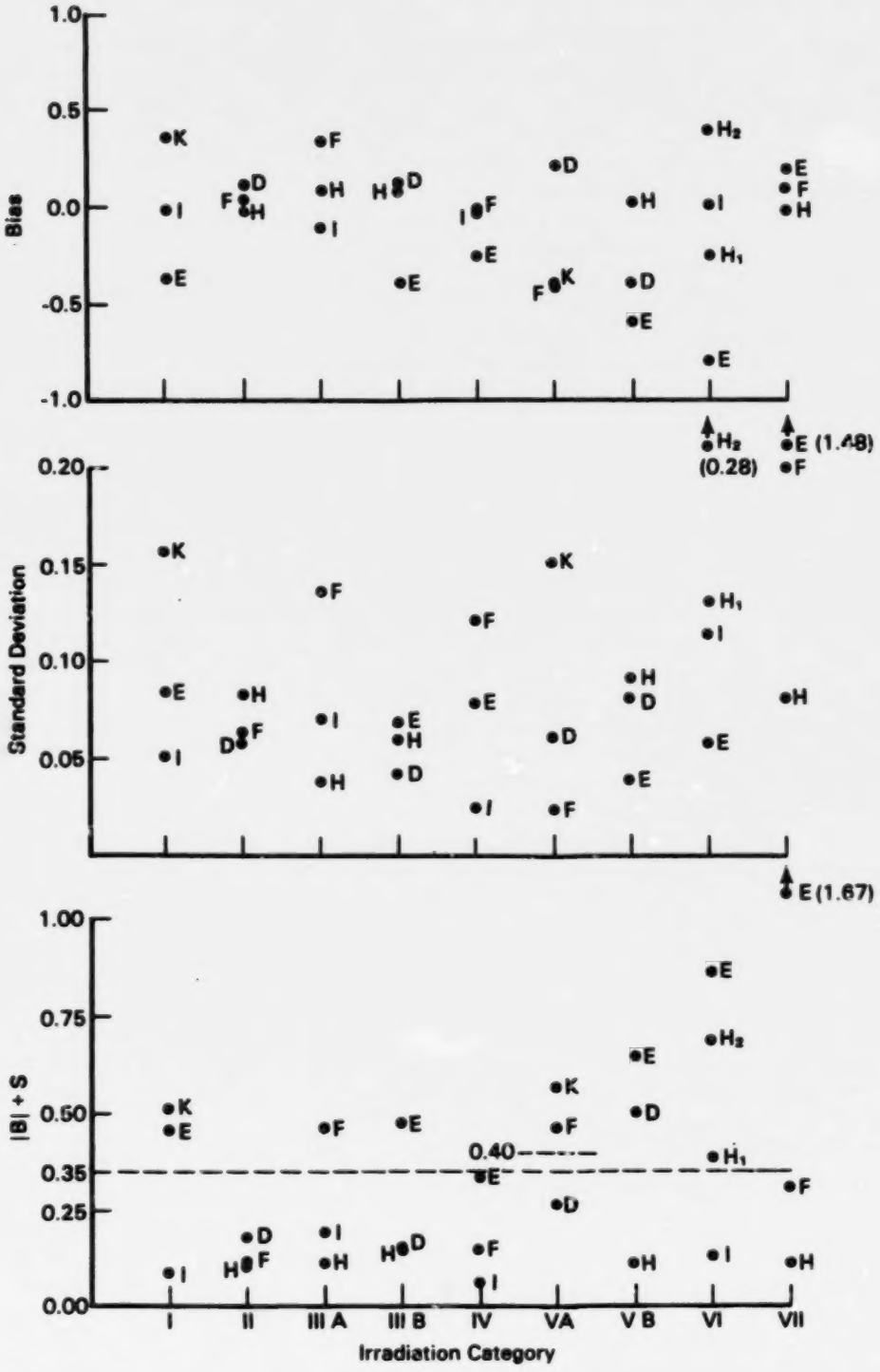

FIGURE 2. Summary of Performance (Wrist Dosimeters)

BEST COPY AVAILABLE

No variation was observed between the results of the ring dosimeters and the wrist dosimeters. Approximately 60% of the dosimeters (61% for the ring dosimeters and 57% for wrist dosimeters) passed at the 0.35 tolerance level (0.40 for Category VA) regardless of whether the dosimeter was a ring or a wrist dosimeter.

It is interesting to note from the data in Figures 1 and 2 that the results tend to be processor-dependent. Some processors, for example processors H, D, G, and B for the rings and processor I for the wrist dosimeters consistently passed each category they entered. Other processors, such as processor A, C, and E for the rings and processors E and K for the wrist dosimeters, consistently failed or at the best barely passed in each category in which they submitted dosimeters. In several cases, the processor's data exhibited standard deviations that were not abnormally high and that were in the range of the standard deviations exhibited by processors that continually passed. The biases, however, tended to fall on the extreme end of the range of biases exhibited by other processors.

The effect of the variation in source was examined for Categories IIIA, IIIB, VA, VI and VII. Figure 3 illustrates the variation in the bias and standard deviation for each of the sources used in the multiple source categories. Each data point is based on the results of one round of testing. In some categories, the same source was used for two of the three rounds. In these cases, twice as many data points are shown, corresponding to each source. The only category that showed a definite variation in the results because of a variation in source was Category VA. As evident in Figure 3, the bias resulting from the irradiations with ^{204}Tl were much higher than those resulting from irradiation with ^{90}Sr-^{90}Y. Only one dosimeter irradiated to ^{204}Tl gave a bias within the range of the biases measured for the dosimeters irradiated to ^{90}Sr. The standard deviations, however, were in the same range for the thallium as that covered by the strontium/yttrium. Because the sources used for the irradiations were not disclosed to the processors, it is possible that the processors applied the same calibration factor to the ^{204}Tl as they did for the ^{90}Sr-^{90}Y irradiations. This would result in severely underestimating the dose as was observed in most cases. Based on the results of the Round 2 irradiations, if all three rounds had been irradiated to the ^{204}Tl source, none of the ring dosimeters and only one of the wrist dosimeters would have passed this category.

Figure 3 also illustrates the variation in the bias and standard deviation for the various mixtures of sources used in the mixture category (VII). The number of data points is small. However, it appears that the absolute values of the biases tend to be larger for the mixture containing neutrons than for the other three mixtures, especially the mixture of Categories III and IV where the biases are quite low.

BEST COPY AVAILABLE

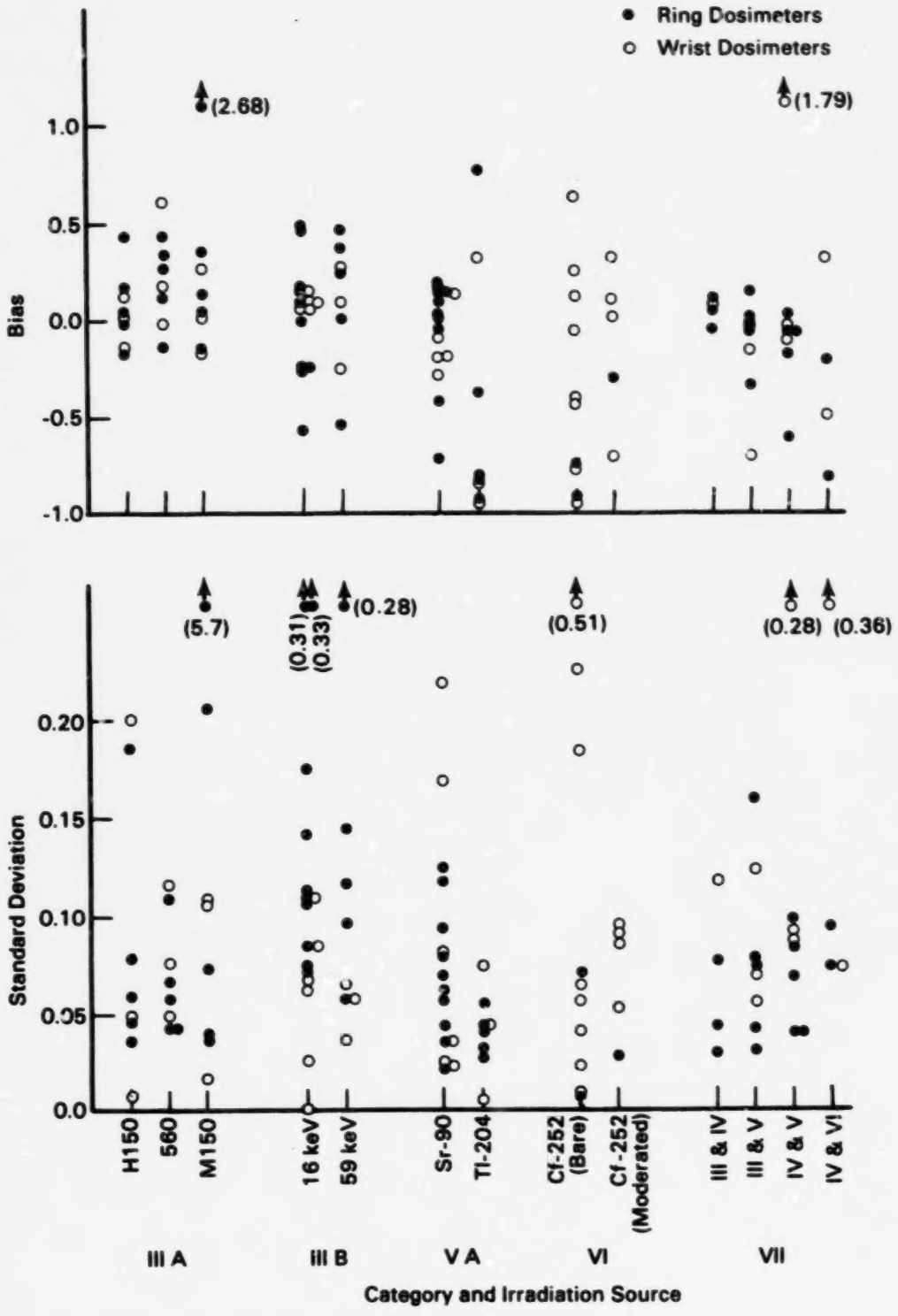

FIGURE 3. Variation in Performance Based on Source (Categories IIIA, IIIB, VA, VI, and VII)

BEST COPY AVAILABLE

APPROPRIATENESS OF THE DRAFT STANDARD

The appropriateness of the draft standard must be determined before it can be used to conduct performance testing of extremity dosimeter processors. The evaluation of the draft standard encompasses three areas: the test procedures, the performance criterion, and the tolerance level.

THE TEST PROCEDURES

The procedures used during the performance testing will affect the results of the testing. It is, therefore, important that the procedures are appropriate for extremity dosimeters. Three areas are presented that require further consideration.

The first area is the identification of irradiation categories to the processors. Although the most recent draft of the standard does not address the identification of the dosimeters irradiated in each category to the processors, previous drafts specified that only those dosimeters irradiated in the accident categories, in the neutron irradiation category (Category VI), and in the mixture categories using neutron irradiations be identified to the processors. The dosimeters irradiated in the remaining categories are not identified until after submission of the test results. This specification is also present in ANSI N13.11. However, for this evaluation of the draft standard, the decision was made to identify the dosimeters that were irradiated in each of the categories, although the source and the dose levels were not identified. This decision was based on two reasons.

First, conversations with processors indicated that in actual practice the source or sources are often identified and this information communicated to the processor. Unlike whole body dosimetry where the dosimeter may be worn in a variety of radiation environments for an entire calendar quarter, extremity dosimeters are frequently assigned for specific tasks where the extremity dose is expected to be significant. In these cases, the source of the radiation is more easily identified and the processors may have an indication of not only the irradiation category, but frequently of the irradiation source. The extent to which the processors are knowledgable of the source should be determined before finalizing the draft standard. The second reason involves the problems inherent in the discrimination of the energy spectra by dosimeters, especially those dosimeters that are composed of only one element. Although variations in the design of the dosimeter will affect the response of the dosimeter, single chip dosimeters calibrated to ^{137}Cs can underrespond to low-energy photons by a factor of 3 or more (Reece et al. 1985). The response to beta radiation can be even worse. This variation in response to sources in different categories is in many cases significantly greater than the 30% uncertainty in the accuracy allowed in the draft standard.

The second area for consideration is the identification of the neutron spectra. In Category VI (neutrons) the processor was informed of the actual source that was used (moderated ^{252}Cf versus unmoderated ^{252}Cf). Without the

BEST COPY AVAILABLE

knowledge of the type of neutron spectra, determination of the neutron dose equivalent would also have a considerably large error. Therefore, the results for Category VI are much better than expected had the processors not known the spectra.

The third area for consideration is the selection of the source. The draft standard currently specifies that except for the category specifically identified as that dealing with radiation mixtures, only one type of radiation and one energy spectrum should be used per category in a given testing period. It further specifies that for multiple-source categories, the source should be randomly selected. These specifications may cause the results of one testing period to vary substantially from the results of another, especially in Category VA, where the performance of dosimeters irradiated to $^{90}Sr/^{90}Y$ varied considerably from the performance of dosimeters irradiated to the ^{204}Tl source. Even at the higher tolerance level of ^{204}Tl (0.40), it was difficult for the processors to meet the criterion. An alternative might be to alternate the source for each round in multiple-source categories with two or three sources. In Category IIIA and the mixture category involving Category IIIA, the source could be chosen randomly for each round, without replacement as specified in the DOE Standard (DOE 1986).

THE PERFORMANCE CRITERION

Evaluation of the appropriateness of the draft standard includes an evaluation of the appropriateness of the performance criterion. As stated earlier, the goal of the performance criterion was that the accuracy of the annual assignment of dose equivalent should be within 30% of the conventionally true value for 95% of the personnel receiving in excess of one-tenth of the maximum permissible dose equivalent.

Depending on the assumptions, the performance criterion can be interpreted in several ways. For 15 individual dosimeter readings, there is an approximately 70% confidence that the response of any given dosimeter will be within 30% of a conventionally true value. Thus, the reported dose equivalent for a worker receiving all of the annual dose on one dosimeter would have an approximately 70% confidence of meeting the requirement. However, if the worker exchanged dosimeters on a quarterly basis and received approximately equal dose on each of the four dosimeters, there would be approximately a 95% confidence that the annual reported dose equivalent from a given dosimeter would be within 30% of a conventionally true value. This latter interpretation is the one upon which the draft standard is based.

There are several areas of inconsistency resulting from the use of this performance criterion. First, while personnel dosimeters used to measure whole-body dose are commonly exchanged on a calendar quarter basis, the exchange rate for extremity dosimeters is not as predictable. A survey of extremity dosimetry practices at DOE facilities (Harty, Reece and MacLellan 1986) indicated that of 24 respondents, 3 exchanged extremity dosimeters on a quarterly basis, 10 exchanged dosimeters on a monthly basis, 1 exchanged on a biweekly basis, 1 exchanged dosimeters on a daily basis, and 9 responded that

BEST COPY AVAILABLE

they exchanged extremity dosimeters after completing a job with significant exposure potential. Thus the assumption of quarterly dosimeter exchanges may not be valid. In addition, because extremity dosimeters are often assigned on a "per job" basis and are commonly assigned only to personnel expected to receive a significant extremity exposure, the assumption of approximately equal dose on each assigned dosimeter may not be appropriate. These two assumptions should be reinvestigated. If the assumption of approximately equal dose is found to be invalid, the confidence will decrease.

A second area of inconsistency is the inclusion of accident dosimetry and nonaccident dosimetry under the same performance criterion. The performance criterion in the draft standard assumes four dosimeter readings in a year and an approximately 95% confidence that the annual reported dose equivalent would be within 30% of the conventionally true value. However, high doses in the accident range are typically received by only one dosimeter. Thus, for the accident categories, there would only be 70% confidence that the reported dose is within 30%.

A third area of inconsistency is the specification of the test range. The test range for the non-accident dosimetry (as specified in the draft standard) has a lower range of 0.25 rem [0.15 rem for Category VA (beta particles)]. This lower range is not consistent with the wording of the goal of the performance criterion regarding personnel receiving in excess of one-tenth of the maximum permissible dose equivalent. Assuming a monthly dosimeter exchange (although the draft standard assumed a quarterly exchange), one-tenth of the MPD is 0.6 rem per dosimeter. This is above the 0.25 lower dose range specified in the draft standard. The lower range is in part a concession to the long lengths of time required to irradiate to higher doses using the sources specified in the draft standard. Doses in the range of 0.25 rem are not expected to exhibit much variation in uncertainty from doses in the range of 0.6 rem. The performance criterion, however, should be reworded.

Although the performance criterion is based upon recommendations in ICRU Report 20 (ICRU 1971) and in NCRP Report 57 (NCRP 1978), the International Commission on Radiological Protection (ICRP) in Publication 35 (ICRP 1982) has also made recommendations on the uncertainty in the annual reported dose equivalent. These recommendations should be considered in the formation of appropriate performance criteria for extremity dosimeters. The ICRP recommends that the uncertainty in the annual reported dose equivalent be reduced as far as reasonably achievable. It further recommends that the uncertainties should not exceed a factor of 1.5 at the 95% confidence level when the dose equivalent is on the same order as the annual maximum permissible dose, or a factor of 2 at the 95% confidence level when the annual reported dose is less than 1 rem. It explicitly states that these accuracy limits include variations in dosimeter sensitivity with incident energy and direction of incidence, as well as intrinsic errors in the dosimeter and its calibration. This approach does not require the use of quarterly dosimeter exchanges with the accompanying assumption of approximately equal doses received each quarter.

BEST COPY AVAILABLE

THE TOLERANCE LEVEL

The magnitude of the tolerance level dictates the stringency of the performance testing. The higher the tolerance level, the larger the number of processors that will meet the performance criterion.

At the current tolerance level (0.35; 0.40 for ^{204}Tl), 61% of the ring dosimeters pass. Table 3 illustrates the effect of raising the tolerance level on the number of ring dosimeters that pass in each category. Raising the tolerance level to 0.50 will cause an additional 10% of the ring dosimeters submitted to pass, for a total of 71% of the ring dosimeters passing. Raising the tolerance level further to 0.65 will pass an additional 10% for a total of 80% of the ring dosimeters.

For the wrist dosimeters, 57% pass at the 0.35 (0.40 for ^{204}Tl) tolerance level. Table 3 indicates that raising the tolerance level to 0.50, an additional 22% of the wrist dosimeters will pass for a total of 79% of the wrist dosimeters. If the tolerance level is raised to 0.65, an additional 10% of the wrist dosimeters will pass for a total of 89% of the wrist dosimeters.

The tolerance level could be relaxed to allow more processors to meet the performance criterion. The tolerance level in ANSI N13.11 is set to 0.5 for protection categories (not including accident categories), which is less stringent than the tolerance level for extremity dosimeters given in the draft standard. ANSI N13.11 applies to whole-body dosimeters. However, extremity dosimeters are often simple modifications of whole-body dosimeters (Harty, Reece, and MacLellan 1986) and thus justification is available for relaxing the tolerance level in the draft standard at least to the level specified in ANSI N13.11 for whole-body dosimeters.

However, it is necessary to determine why some processors failed based on the current performance criterion before a final decision can be made regarding what tolerance level is appropriate. While the performance criterion proposed in the draft standard does not place a constraint on the precision (reflected by the standard deviation) as is done in NCRP Report 57 (NCRP 1978), there is an implied constraint on the standard deviation of about 0.12 to 0.15. Larger values of the standard deviation do not allow sufficient latitude for a minimal uncertainty in the bias (DOE 1986). Of the 16 ring dosimeters that did not pass at the 0.35 (0.40 for Category VA) level, 10 (or 62%) had standard deviations below 0.15. The absolute value of the biases ranged from 0.3 to 0.7 for these dosimeters. For the 12 wrist dosimeters that did not pass at the 0.35 (0.40 for Category VA) level, 8 (or 66%) had standard deviations below 0.15. The absolute value of the biases ranged from 0.25 to 0.80 for these dosimeters. This indicates that approximately two-thirds of the dosimeters that did not pass, failed as a result of the bias.

The bias (as used in this report) is a measure of the average fractional difference between the delivered and the reported absorbed dose or dose equivalent of 15 dosimeters. The bias is a crucial aspect of a measurement; a series of measurements may have excellent precision, but if the answer is not close to the actual value, its usefulness is limited. Fortunately, if the

BEST COPY AVAILABLE

TABLE 3. Fraction of Processors Passing at Specific Tolerance Levels

Category	Rings			Wrist			Total		
	0.35	0.50	0.65	0.35	0.50	0.65	0.35	0.50	0.65
I	0.4	0.6	1.0	0.33	0.66	1.0	0.38	0.62	1.0
II	0.8	NC[a]	NC	1.0	NC	NC	0.88	NC	NC
IIIA	0.6	0.8	NC	0.66	1.0	NC	0.62	0.88	NC
IIIB	0.8	NC	0.8	0.66	1.0	NC	0.62	0.75	0.88
IV	0.6	NC	0.8	1.0	NC	NC	0.75	NC	0.88
VA[b]	0.8	NC	NC	0.33	0.66	1.0	0.62	0.75	0.88
VB	0.4	0.8	NC	0.33	0.66	1.0	0.38	0.75	0.88
VI	0[c]	NC	NC	0.25	0.50	NC	0.20	0.40	NC
VII	0.8	NC	NC	0.66	NC	NC	0.75	NC	NC
TOTAL	0.61	0.71	0.80	0.57	0.79	0.89	0.59	0.74	0.84

(a) NC = No change from previous level.
(b) The results from Category VA are compared against tolerance levels of 0.40, 0.55, and 0.70 even though the ^{204}Tl source was used for only one of the three rounds.
(c) Only one ring dosimeter was submitted in Category VI.

BEST COPY AVAILABLE

measurements are reproducible, unacceptable biases can often be improved by calibration using appropriate phantoms and standards.

Although the bias may be affected by factors such as incorrect voltages in readout devices or mathematical errors, the primary cause of the unacceptable bias is probably improper calibration. Assuming that the errors occur because of incorrect calibrations, providing a means for the processors to calibrate their results and correct the bias, such that the bias will be less than 0.20 (assuming the standard deviations found in this study do not vary), would result in approximately the same number of processors passing the test (86%) as would occur if the tolerance level were raised to 0.65. However, for single chip dosimeters, variations in the bias may not be easily corrected for some multiple source categories because of variations in the dosimeter response due to differing source energies. In addition, the improvement of the bias after calibration presupposes that in subsequent tests the dosimeters that are irradiated in each category are identified to the processors as occurred in this test study. Single chip dosimeters in particular are unable to discriminate between radiation sources and the resulting error can be large as explained earlier.

After correction of the biases, it may be appropriate to assign separate tolerance levels for extremity dosimeters. The lower (more stringent) level would apply to multielement dosimeters that can be used to distinguish between radiation type and energy spectra and to single chip dosimeters in cases where the irradiation source has been identified. The higher (less stringent) tolerance level would apply to single chip dosimeters where it can be demonstrated that the processor is unable to identify the irradiation source.

BEST COPY AVAILABLE

CONCLUSIONS AND RECOMMENDATIONS

Using the performance criterion and tolerance level given in the draft standard (HPSSC P/N 13.32, "Standard for the Performance Testing of Extremity Dosimeters" June 21, 1984) 61% of the ring dosimeters and 57% of the wrist dosimeters passed the performance test. Of those dosimeters that did not pass, approximately two-thirds exhibited standard deviations below 0.15 with the biases accompanying these standard deviations ranging from 0.25 to 0.80. This indicates that approximately two-thirds of the dosimeters that did not pass, failed as a result of the bias. This observation is further validated because the results tended to be processor-dependent. Some processors consistently passed each category they had chosen, while others consistently failed, or at best barely passed. These latter processors frequently exhibited standard deviations that were not abnormally high and that fell in the range of the standard deviations exhibited by processors that passed. The biases, however, tended to fall on the extreme end of the range of the biases exhibited by passing processors. This indicates that the major source of error for failing processors is the bias, which is influenced primarily by the calibration.

Recommendations for improving the bias and thereby improving the performance of the processors involves providing calibrations to the processors using appropriate standards and phantoms. The calibrations would be followed by another set of performance tests to determine the improvement achieved. The study should be enlarged to include additional processors to ensure that a representative sample has been obtained. Visits to some of the processors that participated in this study would also be appropriate to determine what fraction of the error was caused by calibration errors as well as to identify other possible sources of error.

It is further recommended that the draft standard be re-evaluated to ensure that it is appropriate for the performance testing of extremity dosimeters. This evaluation should encompass the testing procedures, the performance criterion, and the tolerance level. Specific items that should be examined include:

Testing Procedures

- the extent to which processors of extremity dosimeters are aware of the exposure sources during irradiation in the workplace
- the magnitude of the error resulting from not identifying the irradiation categories (excluding accident and neutron irradiation categories) for single chip dosimeters and a comparison of this error with the tolerance level set in the draft standard
- the selection of sources in multiple source categories.

BEST COPY AVAILABLE

Performance Criterion

- an investigation of the dosimeter exchange rate (the number of dosimeters worn annually by a given individual) to verify or discount the assumption of four dosimeter exchanges a year
- an investigation of the validity of the assumption of approximately equal doses on each of the extremity dosimeters worn by a single individual during a given year
- the inclusion of accident and nonaccident dosimetry under the same performance criterion.

Tolerance Level

- the validity of using a more stringent tolerance level (in the non-accident categories) for extremity dosimeters than in ANSI N13.11 (ANSI 1983) for whole body dosimeters
- the possibility of assigning two separate tolerance levels. The lower level would be used for multielement dosimeters and for single chip dosimeters in cases where the irradiation source has been identified. The higher tolerance level would be used for single chip dosimeters where it can be demonstrated that the processor is unable to identify the irradiation source.

BEST COPY AVAILABLE

REFERENCES

American National Standards Institute (ANSI). 1983. American National Standard for Dosimetry - Personnel Dosimetry Performance - Criteria for Testing. ANSI N13.11-1983. New York.

Code of Federal Regulations (CFR). 1981. 10 CFR Part 20, "Standards for Protection Against Radiation."

Federal Register. 1984. 41 Fed Reg 1205. "Improved Personnel Dosimetry Processing." January 10, 1984.

Federal Register. 1987. 52 Fed Reg 4601. "Improved Personnel Dosimetry Processing." February 13, 1987.

Griffith, R. V., D. E. Hankins, R. B. Gammage, L. Tommasino and R. V. Wheeler. 1979. "Recent Developments in Personnel Neutron Dosimeters - A Review." Health Phys. 36:235-260.

Harty, R., W. D. Reece and J. A. MacLellan. 1986. Extremity Dosimetry at U.S. Department of Energy Facilities. PNL-5831, Pacific Northwest Laboratory, Richland, Washington.

International Commission on Radiological Protection (ICRP). 1982. General Principles of Monitoring for Radiation Protection of Workers. ICRP Publication 35, Pergamon Press, Oxford, Great Britain.

International Commission on Radiation Units and Measurements (ICRU). 1971. Radiation Protection Instrumentation and Its Application. ICRU Report No. 20, ICRU Publications, Washington, D.C.

McDonald, J. C., R. V. Griffith, P. Plato and J. Miklos. 1983. Measurements of Gamma-Ray Dose from a Moderated ^{252}Cf Source. NUREG/CR-2957, PNL-4590, Pacific Northwest Laboratory, Richland, Washington.

National Council on Radiation Protection and Measurements (NCRP). 1971. Protection Against Neutron Radiation. NCRP Report No. 38, NCRP Publications, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1978. Instrumentation and Monitoring Methods for Radiation Protection. NCRP Report No. 57, NCRP Publications, Washington. D.C.

Plato, P., and G. Hudson. 1980. Performance Testing of Personnel Dosimetry Services: Final Report of a Two-Year Pilot Study. NUREG/CR-1064, U.S. Nuclear Regulatory Commission, Washington D.C.

Plato, P., and J. Miklos. 1983. Performance Testing of Personnel Dosimetry Services: Final Report of Test #3. NUREG/CR-2891, U.S. Nuclear Regulatory Commission, Washington D.C.

BEST COPY AVAILABLE

Reece, W. D., R. Harty, L. W. Brackenbush and P. L. Roberson. 1985. Extremity Monitoring: Considerations for Use, Dosimeter Placement, and Evaluation. NUREG/CR-4297, Pacific Northwest Laboratory, Richland, Washington.

Roberson, P. L., K. L. Holbrook, R. C. Yoder, R. A. Fox, R. T. Hadley, B. T. Hogan and C. D. Hooker. 1983. Performance Comparisons of Selected Personnel Dosimetry Systems in Use at Department of Energy Facilities. PNL-3983, Pacific Northwest Laboratory, Richland, Washington.

Roberson, P. L., and K. L. Holbrook. 1984. Guidelines for the Calibration of Personal Dosimeters. PNL-4515, Pacific Northwest Laboratory, Richland Washington.

Roberson, P. L., F. N. Eichner and W. D. Reece. 1986. Determination of Photon Conversion Factors Relating Exposure and Dose for Several Extremity Phantom Designs. PNL-5660, Pacific Northwest Laboratory, Richland, Washington.

Schwartz, R. B., and C. M. Eisenhauer. 1980. The Design and Construction of a D_2O-Moderated ^{252}Cf Source for Calibrating Neutron Personnel Used at Nuclear Power Reactors. NUREG/CR-1024, U.S. Nuclear Regulatory Commission, Washington, D.C.

Schwartz, R. B., and C. M. Eisenhauer. 1982. Procedures for Calibrating Neutron Personnel Dosimeters. NBS Special Publication 633, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C.

Schwartz, R. B., C. M. Eisenhauer and J. A. Grundl. 1983. Experimental Verification of the Neutron Spectrum from the NBS D_2O-Moderated ^{252}Cf Source. NUREG/CR-3399, U.S. Nuclear Regulatory Commission, Washington, D.C.

U.S. Department of Energy (DOE). 1986. Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems. DOE Laboratory Accreditation Program for Personnel Dosimetry Systems. DOE/EH-0027. U.S. Department of Energy, Washington, D.C.

BEST COPY AVAILABLE

APPENDIX A

ASSESSMENT OF UNCERTAINTIES

BEST COPY AVAILABLE

APPENDIX A

ASSESSMENT OF UNCERTAINTIES

The dose equivalent, H, or dose, D, delivered to the sensitive element of a dosimeter can be expressed as follows:

Photon (sealed source):

$$D = \dot{X}(d_c) \cdot C_x \cdot \left(\frac{d_c}{d_p}\right)^2 \cdot \left(\frac{d_p}{d_p - d_e}\right)^2 \cdot f_Q \cdot t + D_B$$

Photon (x-ray):

$$D = T(d_c) \cdot C_x \cdot M \cdot \left(\frac{d_c}{d_p}\right)^2 \left(\frac{d_p}{d_p - d_e}\right)^2 \cdot f_Q \cdot C_{TP} + D_B$$

Beta:

$$D = \dot{D}(d_c) \cdot \left(\frac{d_c}{d_p}\right)^2 \cdot \left(\frac{d_p}{d_p - d_e}\right)^2 \cdot f_Q \cdot t \cdot C_t + D_B$$

Neutron:

$$D = \left(\frac{3600}{4\pi}\right) \cdot N \cdot C_N \cdot t \cdot f_Q \left(\frac{1}{r^2 + r_p^2}\right) \left(\frac{r}{d_p}\right)^2 + D_d$$

where:

$\dot{X}(d_c)$ is the exposure rate at the calibration distance, d_c, without phantom. This quantity is measured with NBS calibrated transfer chambers and verified with the NBS measurement quality assurance program. The uncertainty is systematic.

C_x is the conversion factor from Roentgens to rems in the presence of a of a phantom. The uncertainty for C_x is not included in the uncertainty.

d_c is the distance from the source to the calibration point. Its uncertainty is included in the uncertainty in $X(d_c)$, $T(d_c)$, or $D(d_c)$.

BEST COPY AVAILABLE

d_p is the distance from the source to the phantom surface. It is intended to be equal to d_c (or r). It is explicitly included so that random errors in determining d_p can be included in the uncertainty analysis.

d_e is the distance from the phantom surface to the midpoint of the sensitive element(s) when the dosimeter is mounted on the phantom for irradiation. Dosimeters are mounted parallel to the phantom surface. d_e can have both random and systematic uncertainties.

f_Q is the ratio of the dose rate at the position of the dosimeter to the dose rate at the center of the phantom. It has a systematic uncertainty.

t is the exposure time. The systematic uncertainty is minimized by timing measurements and, if necessary, appropriate correction factors. Random uncertainty is present.

D_B is the difference between the background dose or dose equivalent received by the test dosimeters and that received by the control dosimeters. This may occur during the time the test dosimeters are separated from the control dosimeters during an exposure period, normally less than 8 hours. The uncertainty is random.

$T(d_c)$ is the calibration value for the x-ray technique in units of exposure per charge recorded by the transmission chamber. This quantity is measured with a NBS-calibrated chamber and verified with the NBS measurement quality assurance program. The calibration factors are checked and adjusted quarterly unless problems are indicated by the internal quality control program. The uncertainty is systematic.

M is the reading of the transmission chamber. The uncertainty is random.

C_{TP} is the temperature and pressure correction factor required for the transmission chamber reading. The room conditions are monitored continuously. Most of the uncertainty is random. There may be some systematic uncertainty if the monitoring temperature device is not inside the transmission chamber.

$\dot{D}(d_c)$ is the dose rate measured with an in-house extrapolation chamber or measured by NBS. The in-house extrapolation chamber is calibrated using a source calibrated by NBS or traceable to NBS. The uncertainty is systematic because the calibration is determined before the test irradiations and changed infrequently (e.g., quarterly).

C_t is the transmission factor necessary if the NBS calibration was performed at a different tissue depth than the source calibration. The uncertainty is systematic. This factor is typically identically unity with no uncertainty.

BEST COPY AVAILABLE

N is the neutron emission rate, calibrated by NBS. The uncertainty is due to the NBS calibration and source decay. Source decay uncertainty is small. The total uncertainty is systematic.

C_N is the dose-equivalent conversion factor recommended by NBS. This factor is used by the testing laboratory and the participants, so that no irradiation uncertainty is associated with its use.

r is the theoretical distance to the calibration point. The ratio r/d_p represents the assumed unity value associated with the measurement of the source to phantom distance.

r_p is the distance from the center of the phantom to the dosimeter position. Random uncertainties result from the placement of the dosimeter. Systematic uncertainties occur because of the placement of the position of the sensitive element in the dosimeter.

BEST COPY AVAILABLE

TABLE A.1. Irradiation Uncertainties

Variable	Type	Percent Uncertainty: Bremsstrahlung X-ray (1 m & 2 m)	K X-ray (50 cm)	Neutron (50 cm)	^{137}Cs	^{90}Sr
$T(d_c)$	Sys	1.7[a]	2.3[a]	-	-	-
	Ran	0.5	0.5		-	-
d_p	Ran	0.1	0.4	0.4	0.1	0.6
d_e	Ran	0.1	0.4	-	0.1	0.6
	Sys	0.3	1.2	-	0.3	1.3
f_Q	Sys	1.5	2.0	1.0	0.5	1.0
t	Ran	-	-	0.5	<0.5	<0.5
M	Ran	0.5	0.5	-	-	-
C_{TP}	Ran	0.2	0.2	-	-	-
D_B	Ran	0.3	0.3	0.3	<0.3	<0.3
N	Sys	-	-	1.5	-	-
r_p	Sys	-	-	0.3	-	-
$X(d_c)$	Sys	-	-	-	1.6	-
$D(d_c)$	Sys	-	-	-	-	2.0
Total Systematic		2.3	3.3	1.8	1.7	2.6
Total Random		0.8	1.0	0.7	0.6	1.0
Total S + R		3.1	4.3	2.5	2.3	3.6

(a) 1/2% systematic and 1/2% random reproducibility uncertainty included to allow for the movement of the tube head between Bremsstrahlung and k-fluorescence techniques.

BEST COPY AVAILABLE

APPENDIX B

COMPILATION OF DOSIMETER PERFORMANCE DATA

BEST COPY AVAILABLE

APPENDIX B

COMPILATION OF DOSIMETER PERFORMANCE DATA

This appendix contains the performance data for the dosimeters tested in this study. The results for the ring dosimeters are presented in Tables B.1 through B.9. The results for the wrist dosimeters are presented in Tables B.10 through B.18. The tables are organized by category. Each table contains the processor identification codes (A - K) and dosimeter type codes (A - U) for the dosimeters submitted for that specific category. The tables list the bias and standard deviation for each of the three rounds of testing, as well as the bias, standard deviation, and the sum of the absolute value of the bias and the standard deviation calculated for the entire test.

BEST COPY AVAILABLE

TABLE B.1. Category I - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	|B| + S
A	I	1	M150	-5.57E-01	6.15E-02	-
		2	M150	1.40E-01	4.48E-01	-
		3	M150	-1.10E-01	4.02E-01	-
		Total		-1.76E-01	3.23E-01	4.99E-01
D	J	1	M150	1.67E-01	3.54E-02	-
		2	M150	1.28E-01	6.42E-02	-
		3	M150	1.01E-01	4.25E-02	-
		Total		1.32E-01	4.53E-02	1.77E-01
E	N	1	M150	4.19E-01	1.02E-01	-
		2	M150	2.92E-01	1.18E-01	-
		3	M150	5.32E-01	1.33E-01	-
		Total		4.14E-01	1.10E-01	5.24E-01
F	T	1	M150	2.60E-01	1.24E-01	-
		2	M150	5.40E-01	1.23E-01	-
		3	M150	1.09E-01	5.40E-01	-
		Total		3.03E-01	3.03E-01	6.06E-01
H	D	1	M150	1.42E-01	3.30E-02	-
		2	M150	2.50E-01	1.24E-01	-
		3	M150	1.27E-01	1.44E-01	-
		Total		1.73E-01	1.03E-01	2.76E-01

BEST COPY AVAILABLE

TABLE B.2. Category II - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
A	I	1	^{137}Cs	-7.53E-01	1.04E-01	-
		2	^{137}Cs	-4.67E-01	1.35E-01	-
		3	^{137}Cs	-4.65E-01	1.40E-01	-
		Total		-5.61E-01	1.18E-01	6.80E-01
F	T	1	^{137}Cs	-2.04E-02	2.39E-01	-
		2	^{137}Cs	1.97E-01	8.99E-02	-
		3	^{137}Cs	1.41E-01	9.54E-02	-
		Total		1.06E-01	1.46E-01	2.52E-01
G	A	1	^{137}Cs	-2.40E-01	4.19E-02	-
		2	^{137}Cs	1.78E-02	3.24E-02	-
		3	^{137}Cs	-2.28E-02	3.55E-02	-
		Total		-8.18E-02	3.41E-02	1.16E-01
J	Q	1	^{137}Cs	9.36E-02	8.22E-02	-
		2	^{137}Cs	-1.37E-01	5.62E-02	-
		3	^{137}Cs	6.42E-02	1.17E-01	-
		Total		7.09E-03	8.20E-02	8.91E-02
K	H	1	^{137}Cs	-1.31E-01	1.64E-01	-
		2	^{137}Cs	-1.43E-01	1.25E-01	-
		3	^{137}Cs	-1.92E-01	1.39E-01	-
		Total		-1.55E-01	1.33E-01	2.88E-01

BEST AVAILABLE

TABLE B.3. Category IIIA - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
D	J	1	H150	-1.15E-02	5.90E-02	-
		2	S60	1.09E-01	4.12E-02	-
		3	M150	3.89E-02	3.54E-02	-
		Total		4.56E-02	4.29E-02	8.84E-02
E	N	1	H150	4.21E-01	1.86E-01	-
		2	S60	4.38E-01	1.09E-01	-
		3	M150	2.68E+00	5.65E+00	-
		Total		1.18E+00	3.02E+00	4.20E+00
H	E	1	H150	3.36E-02	4.75E-02	-
		2	S60	2.66E-01	5.75E-02	-
		3	M150	1.34E-01	7.23E-02	-
		Total		1.45E-01	5.55E-02	2.00E-01
J	Q	1	H150	1.87E-01	7.85E-02	-
		2	S60	3.20E-01	4.10E-02	-
		3	M150	3.52E-01	2.06E-01	-
		Total		2.87E-01	1.20E-01	4.07E-01
K	H	1	H150	-1.84E-01	3.52E-02	-
		2	S60	-1.34E-01	6.46E-02	-
		3	M150	-1.38E-01	3.82E-02	-
		Total		-1.52E-01	4.43E-02	1.97E-01

BEST COPY AVAILABLE

TABLE B.4. Category IIIB - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
A	I	1	16 keV	-5.76E-01	1.75E-01	-
		2	59 keV	-5.24E-01	2.84E-01	-
		3	16 keV	-2.75E-01	3.13E-01	-
		Total		-4.58E-01	2.45E-01	7.03E-01
D	J	1	16 keV	8.79E-02	1.08E-01	-
		2	59 keV	4.76E-03	5.72E-02	-
		3	16 keV	-2.77E-03	6.97E-02	-
		Total		3.00E-02	7.53E-02	1.05E-01
E	N	1	16 keV	4.66E-01	1.09E-01	-
		2	59 keV	2.48E-01	1.46E-01	-
		3	16 keV	4.45E-01	1.42E-01	-
		Total		3.86E-01	1.23E-01	5.09E-01
F	T	1	16 keV	-2.45E-01	1.13E-01	-
		2	59 keV	3.65E-01	9.54E-02	-
		3	16 keV	-2.45E-01	3.32E-01	-
		Total		-4.18E-02	1.94E-01	2.36E-01
H	E	1	16 keV	1.34E-01	7.26E-02	-
		2	59 keV	4.57E-01	1.17E-01	-
		3	16 keV	1.49E-01	8.36E-02	-
		Total		2.47E-01	8.60E-02	3.33E-01

TABLE B.5. Category IV - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	|B| + S
B	B	1	^{137}Cs	5.58E-02	7.05E-02	-
		2	^{137}Cs	-1.76E-02	5.76E-02	-
		3	^{137}Cs	-3.28E-02	5.23E-02	-
		Total		1.79E-03	5.61E-02	5.79E-02
C	L	1	^{137}Cs	1.42E+00	6.13E-01	-
		2	^{137}Cs	2.64E-01	3.13E-01	-
		3	^{137}Cs	-1.90E-01	1.92E-01	-
		Total		4.97E-01	3.82E-01	8.79E-01
C	M	1	^{137}Cs	3.71E-01	3.44E-01	-
		2	^{137}Cs	9.31E-01	2.41E-01	-
		3	^{137}Cs	-1.49E-01	2.76E-01	-
		Total		3.84E-01	2.68E-01	6.53E-01
G	A	1	^{137}Cs	-3.02E-02	6.42E-02	-
		2	^{137}Cs	3.75E-02	3.85E-02	-
		3	^{137}Cs	9.05E-02	1.05E-01	-
		Total		3.26E-02	6.89E-02	1.02E-01
J	Q	1[(a)]	^{137}Cs	-4.23E-02	1.72E-02	-
		2	^{137}Cs	-1.68E-01	8.84E-02	-
		3	^{137}Cs	-1.82E-02	2.71E-01	-
		Total[(b)]		-7.86E-02	1.58E-01	2.37E-01

(a) Round 1 results are based on 4 dosimeter readings.
(b) Total results are based on 14 dosimeter readings.

BEST COPY AVAILABLE

TABLE B.6. Category VA - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	|B| + S
A	I	1	^{90}Sr	-7.25E-01	2.18E-02	-
		2	^{204}Tl	-9.16E-01	4.47E-02	-
		3	^{90}Sr	-4.18E-01	1.17E-01	-
		Total		-6.86E-01	6.78E-02	7.54E-01
B	B	1	^{90}Sr	1.30E-01	4.30E-02	-
		2	^{204}Tl	-3.89E-01	5.63E-02	-
		3	^{90}Sr	1.33E-01	9.28E-02	-
		Total		-4.19E-02	6.24E-02	1.04E-01
D	J	1	^{90}Sr	1.73E-01	6.90E-02	-
		2	^{204}Tl	7.80E-01	4.00E-02	-
		3	^{90}Sr	9.86E-02	6.17E-02	-
		Total		3.50E-01	5.39E-02	4.04E-01
E	N	1	^{90}Sr	-6.04E-02	7.98E-02	-
		2	^{204}Tl	-8.19E-01	3.28E-02	-
		3	^{90}Sr	4.24E-03	3.69E-02	-
		Total		-2.92E-01	5.01E-02	3.42E-01
H	D	1	^{90}Sr	1.62E-02	1.24E-01	-
		2	^{204}Tl	-7.84E-01	2.84E-02	-
		3	^{90}Sr	-5.07E-02	5.73E-02	-
		Total		-2.73E-01	7.43E-02	3.47E-01

BEST COPY AVAILABLE

TABLE B.7. Category VB - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
A	I	1	U-slab	-6.82E-01	2.38E-02	-
		2	U-slab	-6.77E-01	1.48E-01	-
		3	U-slab	-5.95E-01	1.22E-01	-
		Total		-6.51E-01	1.03E-01	7.55E-01
D	J	1	U-slab	-1.51E-01	3.92E-02	-
		2	U-slab	-2.14E-01	1.90E-02	-
		3	U-slab	-2.17E-01	1.83E-02	-
		Total		-1.94E-01	2.53E-02	2.19E-01
F	T	1	U-slab	-5.10E-01	5.23E-02	-
		2	U-slab	-4.17E-01	3.80E-02	-
		3	U-slab	-4.17E-01	5.81E-02	-
		Total		-4.48E-01	4.64E-02	4.95E-01
H	D	1	U-slab	1.36E-01	9.29E-02	-
		2	U-slab	2.54E-01	1.37E-01	-
		3	U-slab	1.01E-01	2.42E-02	-
		Total		1.64E-01	8.94E-02	2.53E-01
K	H	1	U-slab	3.75E-01	1.38E-01	-
		2	U-slab	2.13E-01	4.76E-02	-
		3	U-slab	4.00E-01	8.84E-02	-
		Total		3.29E-01	9.13E-02	4.20E-01

TABLE B.8. Category VI - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
F	T	1	^{252}Cf bare	-9.30E-01	6.08E-03	-
		2	^{252}Cf mod	-3.10E-01	2.69E-02	-
		3	^{252}Cf bare	-7.22E-01	7.12E-02	-
		Total		-6.54E-01	4.08E-02	6.95E-01

TABLE B.9. Category VII - Ring Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
All Mixtures						
A	I	1	^{137}Cs, ^{90}Sr	-6.14E-01	7.12E-02	-
		2	^{137}Cs, ^{252}Cf mod	-8.21E-01	9.55E-02	-
		3	M150, ^{90}Sr	-3.49E-01	1.60E-01	-
		Total		-5.95E-01	1.07E-01	7.01E-01
F	T	1	^{137}Cs, ^{90}Sr	-7.86E-02	9.79E-02	-
		2	^{137}Cs, ^{252}Cf mod	-2.20E-01	7.31E-02	-
		3	M150, ^{90}Sr	4.74E-02	7.39E-02	-
		Total		-8.36E-02	7.63E-02	1.60E-01
No Neutron Irradiations						
D	J	1	^{137}Cs, ^{90}Sr	1.74E-02	4.15E-02	-
		2	S60, ^{137}Cs	3.06E-02	3.03E-02	-
		3	M150, ^{90}Sr	-1.15E-03	4.17E-02	-
		Total		1.56E-02	3.54E-02	5.10E-02
H	D	1	^{137}Cs, ^{90}Sr	-7.00E-02	4.13E-02	-
		2	S60, ^{137}Cs	-7.18E-02	7.75E-02	-
		3	M150, ^{90}Sr	-6.79E-02	3.08E-02	-
		Total		-6.99E-02	4.98E-02	1.20E-01
G	A	1	^{137}Cs, ^{90}Sr	-1.86E-01	8.44E-02	-
		2	S60, ^{137}Cs	8.86E-02	4.38E-02	-
		3	M150, ^{90}Sr	1.33E-01	7.78E-02	-
		Total		1.18E-02	6.57E-02	7.75E-02

BEST COPY AVAILABLE

TABLE B.10. Category I - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
E	O	1	M150	-2.62E-01	5.36E-02	-
		2	M150	-3.89E-01	7.84E-02	-
		3	M150	-4.60E-01	1.28E-01	-
		Total		-3.70E-01	8.52E-02	4.56E-01
I	R	1	M150	-7.36E-02	6.51E-02	-
		2	M150	1.78E-02	4.53E-02	-
		3	M150	1.30E-04	5.43E-02	-
		Total		-1.85E-02	5.14E-02	6.99E-02
K	G	1	M150	3.90E-01	8.59E-02	-
		2	M150	3.44E-01	1.01E-01	-
		3	M150	3.43E-01	2.64E-01	-
		Total		3.59E-01	1.58E-01	5.17E-01

TABLE B.11. Category II - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
D	K	1	^{137}Cs	1.61E-01	8.21E-02	-
		2	^{137}Cs	7.63E-02	2.33E-02	-
		3	^{137}Cs	1.00E-01	6.62E-02	-
		Total		1.13E-01	5.77E-02	1.70E-01
F	U	1	^{137}Cs	-1.27E-01	9.83E-02	-
		2	^{137}Cs	1.69E-01	4.26E-02	-
		3	^{137}Cs	1.06E-01	5.10E-02	-
		Total		4.94E-02	6.35E-02	1.13E-01
H	C	1	^{137}Cs	-1.86E-02	1.36E-01	-
		2	^{137}Cs	2.71E-02	6.35E-02	-
		3	^{137}Cs	-6.72E-02	4.06E-02	-
		Total		-1.96E-02	8.32E-02	1.03E-01

BEST COPY AVAILABLE

TABLE B.12. Category IIIA - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
F	U	1	H150	1.28E-01	2.01E-01	-
		2	S60	5.92E-01	1.14E-01	-
		3	M150	2.62E-01	1.08E-01	-
		Total		3.27E-01	1.36E-01	4.64E-01
H	C	1	H150	2.82E-02	4.86E-02	-
		2	S60	1.84E-01	4.84E-02	-
		3	M150	1.59E-02	1.66E-02	-
		Total		7.59E-02	3.77E-02	1.14E-01
I	R	1	H150	-1.57E-01	6.66E-03	-
		2	S60	-2.46E-02	7.59E-02	-
		3	M150	-1.45E-01	1.05E-01	-
		Total		-1.09E-01	6.92E-02	1.78E-01

TABLE B.13. Category IIIB - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
D	K	1	16 keV	-9.45E-02	6.65E-02	-
		2	59 keV	2.78E-01	3.68E-02	-
		3	16 keV	1.30E-01	2.62E-02	-
		Total		1.05E-01	4.29E-02	1.48E-01
E	O	1	16 keV	6.34E-02	1.10E-01	-
		2	59 keV	-2.63E-01	6.38E-02	-
		3	16 keV	-1.00E+00	0.00E+00	-
		Total		-4.00E-01	6.82E-02	4.68E-01
H	C	1	16 keV	9.67E-02	7.35E-02	-
		2	59 keV	9.68E-02	5.74E-02	-
		3	16 keV	6.01E-02	6.19E-02	-
		Total		8.45E-02	5.98E-02	1.44E-01

BEST

TABLE B.14. Category IV - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
E	O	1	^{137}Cs	-1.96E-01	1.11E-01	-
		2	^{137}Cs	-2.19E-01	8.19E-02	-
		3	^{137}Cs	-3.25E-01	4.95E-02	-
		Total		-2.47E-01	7.83E-02	3.25E-01
F	U	1	^{137}Cs	-2.12E-01	2.17E-01	-
		2	^{137}Cs	8.73E-02	4.42E-02	-
		3	^{137}Cs	4.64E-02	3.72E-02	-
		Total		-2.60E-02	1.20E-01	1.46E-01
I	R	1	^{137}Cs	-3.10E-02	2.41E-02	-
		2	^{137}Cs	-5.76E-03	2.23E-02	-
		3	^{137}Cs	-7.33E-02	3.05E-02	-
		Total		-3.67E-02	2.40E-02	6.07E-02

TABLE B.15. Category VA - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
D	K	1	^{90}Sr	1.49E-01	8.11E-02	-
		2	^{204}Tl	3.12E-01	7.44E-02	-
		3	^{90}Sr	1.32E-01	2.40E-02	-
		Total		1.98E-01	6.02E-02	2.58E-01
F	U	1	^{90}Sr	-2.85E-01	3.61E-02	-
		2	^{204}Tl	-9.31E-01	4.59E-03	-
		3(a)	^{90}Sr	-8.24E-02	2.37E-02	-
		Total(b)		-4.33E-01	2.32E-02	4.56E-01
K	G	1	^{90}Sr	-2.03E-01	2.19E-01	-
		2	^{204}Tl	-8.35E-01	4.44E-02	-
		3	^{90}Sr	-1.94E-01	1.69E-01	-
		Total		-4.11E-01	1.50E-01	5.61E-01

(a) Round 3 results are based on 4 dosimeter readings.
(b) Total results are based on 14 dosimeter readings.

BEST COPY AVAILABLE

TABLE B.16. Category VB - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
D	K	1	U-slab	-4.22E-01	9.38E-02	-
		2	U-slab	-4.40E-01	1.02E-01	-
		3	U-slab	-3.42E-01	6.18E-02	-
		Total		-4.01E-01	8.13E-02	4.82E-01
E	O	1	U-slab	-5.80E-01	4.93E-02	-
		2	U-slab	-5.92E-01	3.18E-02	-
		3	U-slab	-6.32E-01	3.90E-02	-
		Total		-6.01E-01	3.76E-02	6.39E-01
H	C	1	U-slab	-4.36E-02	8.27E-02	-
		2	U-slab	1.07E-01	1.43E-01	-
		3	U-slab	-6.76E-03	4.33E-02	-
		Total		1.89E-02	9.15E-02	1.10E-01

TABLE B.17. Category VI - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
E	P	1	^{252}Cf bare	-7.52E-01	9.88E-03	-
		2	^{252}Cf mod	-7.05E-01	9.74E-02	-
		3	^{252}Cf bare	-9.39E-01	4.07E-02	-
		Total		-7.99E-01	5.67E-02	8.55E-01
H	F	1	^{252}Cf bare	-4.03E-01	2.26E-01	-
		2	^{252}Cf mod	1.08E-01	8.45E-02	-
		3	^{252}Cf bare	-4.41E-01	2.33E-02	-
		Total		-2.45E-01	1.30E-01	3.75E-01
H	C	1	^{252}Cf bare	2.40E-01	6.38E-02	-
		2	^{252}Cf mod	3.12E-01	5.25E-02	-
		3	^{252}Cf bare	6.21E-01	5.13E-01	-
		Total		3.91E-01	2.78E-01	6.69E-01
I	S	1	^{252}Cf bare	-6.90E-02	5.49E-02	-
		2	^{252}Cf mod	-3.17E-03	9.18E-02	-
		3	^{252}Cf bare	1.17E-01	1.85E-01	-
		Total		1.49E-02	1.14E-01	1.29E-01

TABLE B.18. Category VII - Wrist Dosimeters

Processor Code	Dosimeter Type Code	Round	Source	Bias (B)	Standard Deviation (S)	| B | + S
E	P	1	^{137}Cs, ^{90}Sr	1.79E+00	2.76E+00	-
		2	^{137}Cs, ^{252}Cf mod	-4.95E-01	7.28E-02	-
		3	M150, ^{90}Sr	-7.07E-01	6.97E-02	-
		Total		1.97E-01	1.48E+00	1.67E+00
F	U	1	^{137}Cs, ^{90}Sr	-5.87E-02	8.65E-02	-
		2	^{137}Cs, ^{252}Cf mod	3.01E-01	3.58E-01	-
		3	M150, ^{90}Sr	5.51E-02	5.51E-02	-
		Total		9.91E-02	1.99E-01	2.98E-01
No Neutron Irradiations						
H	C	1	^{137}Cs, ^{90}Sr	-9.03E-02	9.16E-02	-
		2	S60, ^{137}Cs	7.17E-02	1.19E-01	-
		3	M150, ^{90}Sr	-5.16E-02	1.24E-02	-
		Total		-2.34E-02	8.06E-02	1.04E-01

BEST COPY AVAILABLE

DISTRIBUTION

No. of
Copies

ONSITE

50 Pacific Northwest Laboratory

L. W. Brackenbush
G. W. R. Endres
L. G. Faust
J. J. Fix
R. Harty (29)
G. R. Hoenes
C. D. Hooker
K. L. Jones
L. M. Munson
W. D. Reece
P. L. Roberson
J. M. Selby
K. L. Soldat
M. T. Upton
Health Physics Department Library
Publishing Coordination (2)
Technical Report Files (5)

BEST COPY AVAILABLE

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-4959
PNL-6218

2 TITLE AND SUBTITLE
Performance Testing of Extremity Dosimeters

3 LEAVE BLANK

4 DATE REPORT COMPLETED
MONTH: April YEAR: 1987

5 AUTHOR(S)
R. Harty
W. D. Reece
C. D. Hooker

6 DATE REPORT ISSUED
MONTH: June YEAR: 1987

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

8 PROJECT/TASK/WORK UNIT NUMBER
TD-2325

9 FIN OR GRANT NUMBER
FIN B2888

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Regulatory Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a TYPE OF REPORT
Technical

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

The Health Physics Society Standing Committee (HPSSC) Working Group on Performance Testing of Extremity Dosimeters has issued a draft of a proposed standard for extremity dosimeters. The draft standard proposes methods to be used for testing extremity dosimetry systems and the performance criterion used to determine compliance. This study evaluates the draft standard's proposed performance criterion ($|B| + S \leq 0.35$, where B is the bias and S is the standard deviation) against the performance of extremity dosimeter processors. Twenty-one types of extremity dosimeters from 11 processors were irradiated by the Pacific Northwest Laboratory (PNL) to specific dose levels in one or more of seven categories. The processors evaluated the doses and returned the results to PNL for analysis. Approximately 60% of the dosimeters met the performance criterion. Two-thirds of the remaining dosimeters had large biases (ranging from 0.25 to 0.80) but small standard deviations (less than 0.15). Recommendations to improve the biases include providing calibrations (using appropriate irradiation standards and phantoms) followed by another set of performance tests, as well as visiting processors to identify other possible sources of error. It is further recommended that the draft standard be re-evaluated to ensure that it is appropriate for the performance testing of extremity dosimeters.

14 DOCUMENT ANALYSIS - a KEYWORDS/DESCRIPTORS
Extremity
Extremity Dosimetry
Peformance Testing

b IDENTIFIERS/OPEN-ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page) Unclassified
(This report) Unclassified

17 NUMBER OF PAGES

18 PRICE

U.S. GOVERNMENT PRINTING OFFICE: 1987-181-582:60137

50

BEST COPY AVAILABLE